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Optimizing Wastewater Treatment

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OPTIMIZING WASTEWATER TREATMENT

INDEPENDENT STUDY SUBMITTED TO

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Introduction

Public works administrators are responsible for managing publicly owned treatment works, which include water and wastewater treatment facilities. They provide direction and set priorities for employees and the works' systems and processes. There are many legal and political demands placed on them and the organization. Pressures on the organization come from political groups, state health department officials, the federal Environmental Protection Agency, local citizens and environmental groups. These pressures come with expectations for effectiveness, efficiency – low cost and effectiveness – the elimination of odors. They have to comply with increasingly stringent Environmental Protection Agency laws. It is not an easy task to satisfy all these demands and pressures. Benchmarking can be used to help optimize a water utility and to aid in meeting customer and government expectations, demands, and to satisfy political pressures.

This study examines benchmarking and how decision makers can use benchmarking to help track, control, and/or lower costs associated with wastewater treatment. Decision makers have to make tough and sometimes unpopular decisions. They can use benchmarking to help inform them so that they make good decisions, which will help the organization remain viable in today's competitive market. Benchmarking helps to find and incorporate best practices - innovative ways to do things by looking at what others in like facilities do that is effective and efficient while protecting public health and waters. Managers can check their current performance, identify areas needed for improvement, and apply best practices that will lead to superior performance. Benchmarking can lead to high performance by providing decision makers with information that results in proactive versus reactive policies. Looking at budgets/expenses from comparable wastewater treatment plants will help identify areas to improve performance. The financial data used for this study are from the City of

Bismarck's Water Utility Department from 1995 through year 2000. The data are compared with a benchmarking study done by the Water Environment Research Foundation in 1996 using 1995 data. The areas that were investigated are wastewater treatment operations, biosolids, and maintenance and odor control.

This study examines benchmarking as a tool in the wastewater treatment process. Benchmarking will provide tracking for cost trends and optimization changes at the wastewater treatment plant and it will document plant performance. It will bridge the knowing with the doing and thus increase the likelihood of meeting or exceeding wastewater discharge permit limits now and in the future. The overall goal is to treat the wastewater effectively and efficiently before discharging this water back into our public streams, rivers, and waterways so it will not harm the environment or potential drinking water source for people living downstream. Benchmarking will set a baseline that the facility can use to measure against. When wastewater treatment management makes policy changes that affect the process and procedures, then management can measure the effects that the policy has had on the operation costs.

In the United States, wastewater treatment plants by law have to treat the water before it can be discharged back into the environment through EPA pressures. They are required to have a permit to discharge treated water, which stipulates a set of minimum standards that they have to be met. Treating wastewater is one of those necessary evils like having to do laundry. Wastewater is polluted water, something that is dirty, rotten, nasty, disgusting, and smelly. Wastewater is something that most people forget about after they flush it. However, before it can be disposed of or recycled back into our environment, it must be treated, and this is where the wastewater treatment plant appears.

There are local pressures from citizens who want the wastewater facilities to provide customer service without backups or sanitary sewer overflows, odors, and at a low cost. Benchmarking will help to establish a baseline for current conditions and costs. Costs for operations, maintenance, and biosolids can be looked at in detail to see where their time is spent. When operational costs rise or decrease for the treatment, managers can compare the costs to the established baseline and national benchmarked data to help them make decisions for projects with priority. When there are high labor-intensive processes and procedures it may be prudent to automate, change methods or treatment process. The time spent on proactive or preventative maintenance should be more than that time done for reactive or emergency. It is more cost efficient to be proactive with maintenance than reactive.

There are local pressures from citizens who want the wastewater facilities to control odors. Residents should not even know they live next to the wastewater treatment. If people know all too well they live next to the plant, the treatment facility may be under pressure from citizens to reduce/eliminate the foul odors that may be generated during treatment and/or processing. To help address odor concerns, independent research needs to be done on odor control as was conducted in this study on some common processes and techniques used in the wastewater industry. These data were used to generate a cost-benefit analysis for common odor control processes. From benchmarking current conditions and costs, it is evident by the data where the treatment is necessary and what treatment will be most effective and efficient.

Congressional Pollution Intervention

There are many regulatory pressures placed on administration and the wastewater treatment facilities treating the wastewater. These regulatory pressures were started by the U.S. Congress with the Clean Water Act and its amendments. Because of these pressures, there has been dramatic improvement in water quality in the United States because of the cooperative efforts by the federal, state, tribal, and local governments and communities implementing public health and pollution control programs established by U.S. Congress.

The first major U.S. federal legislative attempt to address water pollution was in 1899 and it was called the Rivers and Harbors Act. The purpose of this act was to promote commerce, however it did little to stop the flow of pollution into the national waterways.[1] In 1948 the Water Pollution Control Act was passed. Here the federal government offered state and local governments technical assistance and funds to promote efforts to protect water quality.[2] In 1965, Congress passed the Water Quality Act. It charged states with setting water quality standards for interstate navigable waters.[3]

In 1972, Congress passed the Clean Water Act, which established a national objective to restore and maintain the chemical, physical, and biological integrity of the nation's surface waters. Congress enacted this comprehensive national clean water legislation in response to growing public health concern for serious and widespread water pollution. The Clean Water Act is the primary federal law that protects the health of our nation's waters, including lakes, rivers, and coastal areas. In addition to strengthening the nation's water quality standards system, this landmark legislation does the following: makes illegal the discharge of pollution without a permit, encourages the use of the best achievable pollution control technology, and provides billions of dollars for construction of sewage treatment plants.[4] The Clean Water Act amendment that was passed in 1977 set the groundwork for regulating pollutant discharges into U.S. waters. It strengthened controls on toxic pollutants and allowed states to assume responsibility for federal programs.

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[1] The Clean Water Act A Snapshot of Progress in Protecting America's Waters http://www.epa.gov/owow/cwa/25report.html November 2001

[2] Ibid
[3] Ibid
[4] Ibid

In 1987, the Clean Water Act was reauthorized and focused on sewage treatment plants, toxic pollutants, and authorized citizen suit provisions. It established a renewed focus on achieving the Clean Water Act water quality goals through the following: supporting new state and local efforts to deal with polluted runoff, creating revolving loan funds to provide ongoing support for the construction of treatment plants, catalyzing action to address pollution from urban runoff, and creating programs to protect estuaries of national importance.[5] In 1990, the Coastal Zone Act was reauthorized, which focused the efforts on reducing polluted runoff in 29 coastal states.[6]

The Clean Water Act has standardized the playing field for public owned treatment works (POTW) facilities and industrial users that discharge their wastewater to the POTW for treatment. Since minimal treatment level is standardized throughout our nation, each POTW can benchmark its processes for at least those requirements. Categorical industries, like metal finishers, throughout the nation must meet or exceed federal standards set for their industry before discharging their wastewater to a public owned treatment works. The categorical discharger must meet chemical limitations or government regulators will require them to take appropriate action for any permit noncompliance. Managers and decision makers of public works owned facilities are required to take appropriate actions and steps necessary to bring any chemical, biological or treatment limitation that is out of compliance relating to its permit back into compliance. With any persistent violation or noncompliance, government pressures and intervention will require the public works owned facility to get back into compliance through compliance order and/or enforcement action. Benchmarking is a tool that managers and decision makers can use that changes the public owned treatment works management process from reactive to proactive, therefore the use of benchmarking will increase the likelihood of compliance of federal water quality standards and laws.

[5] Major Legislative Milestones In Protecting the Nation's Waters http://www.epa.gov/OWOW/cwa/timeline.html November 2001
[6] Ibid

The clean water program assesses diverse and cumulative water quality problems on a watershed scale. Each act's passage has enhanced previous improvements to clean the national waterways of pollution. The Clean Water Act looks at the big picture to restoring surface water, wetlands, drinking water, and other aspects of a healthy aquatic system. The clean water programs focus on identifying specific water bodies that cannot support basic uses like fishing, swimming, and developing plans for restoring their health. States will assess problems and determine the water pollution reduction goals for each water body. Federal, state, local, and tribal governments work in partnership with local communities to achieve clean and healthy rivers, lakes, and bays. Despite the progress in reducing water pollution, about one-third of waters surveyed by states do not meet water quality goals.[7]

Even with the Clean Water Act in place and satisfying the federal Environmental Protection Agency, there are still other political demands placed on wastewater treatment plants and the organization. Pressures to the organization come from political groups, state health departments officials, local citizens and environmental groups. These pressures come with expectations for effectiveness, efficiency – low cost, and without the presence of odors. Benchmarking wastewater treatment processes will help facilities to optimize procedures and become effective and efficient at what they do.

Methods to Improve Municipal Effectiveness and Efficiency

A benchmarking study is typically the start of a performance improvement effort. It identifies costs over time and practices for the utility and compares this with others. It is often performed within the context of a larger strategic planning initiative or management review. Benchmarking will

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[7] Clean Water Act Future Challenges http://www.epa.gov/owow/cwa/future.html November 2001

identify "What do we need to improve?" The positive outcome for the public would be lower rates for wastewater treatment, increased attractiveness for new business, and improved quality of live.

Benchmarking incorporates plant optimization through innovative ideas. Plant optimization, uses both engineering and evaluation of the managerial policy. Optimization evaluates staffing levels and operating procedures, as well as identifying treatment process modifications, which could save electricity, chemicals, and labor. Plant optimization can improve efficiency by reducing costs associated with treatment. Benchmarking establishes a baseline from which to measure ongoing performance.

Many wastewater utilities spend a significant portion of their operations budget on electricity. Benchmarking these costs is the first step to optimizing the processes. Energy efficient motors and energy generation from byproduct gas may produce substantial savings in electrical costs. Energy savings could significantly improve operation costs and efficiency.[8] The actual benefit for reduced energy costs to each individual wastewater utility will vary and is dependent on the amount of electric powers required and the geographical location of the facility.[9]

Effective treatment may rest on the amount and type of wastewater a wastewater facility has to treat. Wastewater treatment systems and treatment plants may have ineffective treatment due to hydraulic overloading. Hydraulic overloading demands may be caused by new industry, infiltration, inflow, groundwater through sump pumps, or by unexpected population growth. If ineffective treatment is caused by high flow due to inflow and infiltration into the collection system, this inflow and infiltration should be properly managed so it will not overload the system. John Fisher with the

[8] Water and Wastewater Facilities Will Benefit in a Deregulated Electric Utility Market http://news.wateronline.com/content/news/article.asp?DocID={581BDCCA-99E2-11D3-9A6C-00A0C9C83AFB}&Bucket=Feature+Articles Nov 2001

[9] Davis, Gary, "Water and Wastewater Facilities Will Benefit in a Deregulated Electric Utility Market" November 1999, ESE Associate Vice President, Director of Water/Wastewater Services

consulting engineering firm Short Elliot Hendrickson Inc. said, "When a facility corrects the obvious problems relating to inflow and infiltration, other non-obvious problems would show themselves. For example, one can expect cross connection between storm water to sanitary wastewater to exist, but have to be discovered." The storm sewer is meant to carry water from rain and the sanitary sewer wastewater. These are two different systems and cross connections must not exist. Industrial or commercial loadings may have an impact that the treatment plant cannot effectively treat. Industrial, commercial and plant influent data need to be tracked to create a baseline and on a continuous basis for benchmarking in the future.

Public water utilities may be inefficient and/or ineffective because they do not monitor process control variables. Water utility problems can arise when operations do not monitor the right variables, do not have a clear understanding of the numerous processes at their plants and the interactions among those processes, and are only reactive to process control. To control process variability one must quantify it. It is impossible to control what is not measured. An excellent charting technique to measure variability, called statistical process control (SPC), was developed in the 1920s at Bell Labs by Walter Shewhart. SPC consists of defining work into a series of processes. The process involves mapping or describing each process, identifying quality characteristics for each process, collecting statistical data on the quality characteristics in the form of process charts, and identifying variation in the behavior of the quality characteristics and then taking action to regulate or eliminate the variation. This entails a shifting of focus from product to process.[10]

Instead of focusing on the product, plant operators should focus on controlling the treatment process. This has long been a strategic focus in the manufacturing and industrial sectors, because it yields efficiency and substantial cost savings. The objectives of process control are to dampen

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[10] Houston-Benchmarking Wastewater Treatment Plant Operations http://twri.tamu.edu/watertalk/archive/1998-Feb/Feb-5.2.html November 2001

influent variation, minimize effluent variation, and prevent or recover from process upsets. Variability is the key to two of these objectives and reducing variability is the key to plant optimization.[11]

This study argues that benchmarking would be useful to improve the performance of public utilities. Since it would be a change in their standard operating procedures, there may be resistance to change. Tom Peters has recommended ways to deal with resistance to change. Good communication within the organization and other organizations will improve effectiveness and efficiency. Responsible and proper management and leadership in the water utility industry can lead to changes that will induce creativity and innovation. The water utility industry needs to attract quality leaders, maintain them, and develop new attitudes. It needs to entice employees to open-up to a new way of thinking about their job, as described by Tom Peters. Mr. Peters, an innovative speaker on leadership, describes himself as a "gadfly, champion of bold failures, prince of disorder, maestro of zest, professional loudmouth, corporate cheerleader, lover of markets, and capitalist."[12] He urges management and employees to accept change as a constant way of life. He encourages people to take risks and prepare to fail; encourage enthusiasm, pride, and celebration; stay up with information and technology. Take the initiative to continue to re-educate yourself, give others credit, have a vision, listen, have pride in one's organization, be flexible, and learn to thrive on chaos and uncertainty. Unglue everything in life and then try to pull it all back together again. He stated, "Unless you walk out into the unknown, the odds of making a profound difference in your life are pretty low."[13] Change seldom happens on bright, sunny mornings when your relationship is at its peak and you just

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[11] Annual Report on Privatization CUPE's Annual Report on Privatization - 1999 In the Public Interest http://www.cupe.ca/pwannualreport.html Nov 1999
[12] Peters, Tom, and Tammy Moseley, http://www.stfrancis.edu/ba/ghkickul/stuwebs/bbios/biograph/peters.htm Nov 1999
[13] Ibid

received a raise.[14] Certainly not all change is good, however one needs to be open minded to challenge the status quo and consider the ideas of colleagues.

Public utility managers and employees, who come from the old school of thought and say we do it this way because that's the way we did it last year, the year before and the past 20 years need to look beyond what they did in the past. It is reasonable to get out of your comfort zone and compromise, develop new perspectives, recognize your own faults and character defects, walk the talk, and accept truthful criticism.

Change can be motivated in several ways and there are several options for managers to use in a changing environment. Option one, is no action, which can lead to non-compliance issues now and/or in the future. Change will therefore be motivated through enforcement, fines, and compliance orders. Option one, is the least desirable option. Option two, is to show how comparable facilities have achieved management goals, reduced costs (long term) and become more effective by using benchmark techniques. Option two, will produce long-term positive results on wastewater treatment effectiveness and efficiency. Other motivational influences may be used in conjunction with benchmarking. Managers can use many different strategies to influence staff. Positive communication, being recognized as being part of a team, positive outcomes or effectiveness, recognition, and appealing to professional values are but a few techniques managers can use to motivate employees.

Kim Sung Young states that the key to effective management is trust.[15] It is hard to put cooperative relations into place and to sustain them without trust between management and labor. To develop trust, management should empower workers with the knowledge and skills of all facets of

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14 Ibid

15 Young, Kim, Transforming Government May 1998 http://www.privatization.org/database/PrivatizationProsAndCons.html Nov 1999

the work process and organizational goals, and allow them to participate in decision-making.[16] Good communication at all levels regarding policy and process helps to establish trust.

To help transform change, facilities need to create a sense of urgency, build leadership throughout the organization, create a vision, communicate with internal staff, community, public, state and federal regulatory agencies, empower action by employees, leverage quick wins, and become self-sufficient in the change process, and train trainers to carry on. This process typically will take 3 – 5 years for attitudes to change.[17]

The most efficient utilities demonstrated many best practices, such as the following: sharing workforce with other utilities or other parts of their organization, proactive influencing of regulatory outcome based on good science, utilizing efficient communications technology and work order generation, understanding asset condition, flow monitoring, and process modeling to optimize asset sizing, managing competition to challenge the work force and outsourcing where this reduces costs, and extensive training, and cross-training.[18]

Utilities may optimize their efficiency by using a best-suited method to purchase equipment, services and supplies. It is not in the best interest always to buy equipment, services and supplies at the lowest cost. It would be better to procure equipment, services, and supplies best suited for the job. Oftentimes best does not necessarily equate to the lowest price. Publicly run utilities need to discover and learn about proven and effective approaches to procurement that compress the business cycle, preserve and enhance competition and promote quality results.[19]

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[16] Ibid

[17] Parker Mary A. Main Stream American Water Works Association, 'Case studies highlight improved performance for water utilities", June 2001 Vol. 45 No. 7

[18] Patrick, Roger, Janet, Rompala et al, *Benchmarking Wastewater Operations – Collection, Treatment, and Biosolids Management,* Water Environment Research Foundation Project 96-CTS-5 1997

[19] Kristof, Dawn, *Utilities Strive to Optimize Purchasing Power,* Water World, November 2001, pg 20.

Utilities need to choose to compete more effectively. A consequence of not working effectively and efficiently can lead to utility privatization or a reduced quality of life. Increased efficiency and constant improvement should be the focus for the utilities' operational and maintenance staff. Staff should look at maintaining or reducing the operations and maintenance budget in a continuing effort to provide their service at the least cost. Municipal operations can enhance performance and lower operating costs by evaluating their operations and comparing their performance and operations with those of other utilities, and committing to a program of constant improvement. This will lead to consistent performance that meets or exceeds state and federal compliance standards. The utility needs to have in place incentives that will create a positive and rewarding atmosphere such as more money or salary, or knowing that a competitive facility will keep out the private sector. If the customers are not happy with the way things are done, they could lobby the city commission to change the system and go to the private sector to operate the facilities and boot out the existing management.

To improve efficiency, publicly owned municipal utilities should conduct self-assessments to analyze their operations and determine which functions are fundamental to the utility and which, if any, are ancillary. A collaboration of utility management and staff is needed to determine functions that can be handled most effectively and cost-efficiently by the utility staff, by outsourcing, or by some other method(s). By carefully assessing their individual circumstances, utilities and the communities they serve can determine the most appropriate approach to bring about better efficiency and economy. This creates a win-win situation for managers, public facility, staff and the public.

Benchmarking

The wastewater industry is experiencing significant changes in its operation and management environments. Managers, faced with reduced financial support, increased water quality regulations, high customer expectations, and more critical oversight, must make their operations more efficient, and competitive. If facilities are not competitive, then the private sector may get a long hard look from administration and city commission. The wastewater industry can use benchmarking, as a method to help optimize their performance, be competitive, and stay in compliance with state and federal laws. Benchmarking is the systematic process of searching for best practices, innovative ideas, and highly effective operating procedures that lead to superior performance, and then applying those practices, ideas, and procedures to enhance the performance of one's own organization.[20] Benchmarking can lead to high performance by providing decision makers with information that results in proactive versus reactive wastewater treatment policies and decision-making.

Performance benchmarking uses both metric and process benchmarking techniques to determine facility performance. Utility managers should look at the entire system that influences the treatment and its processes. Metric benchmarking looks at how much, where, and when. It uses independent variables or explanatory factors to determine high or low cost treatment. High cost wastewater facilities may inherently adapt certain traits such as: not providing scheduled preventative maintenance to the process equipment, prolonging required repairs until equipment fails, failing to plan for needed expansion, upgrading the system or processes, or not using new technology and automation to improve its treatment and efficiency. High costs may also be due to not providing

[20] Patrick, Roger, Janet, Rompala et al, *Benchmarking Wastewater Operations – Collection, Treatment, and Biosolids Management*, Water Environment Research Foundation Project 96-CTS-5 1997

for improvements to programs that control inflow and infiltration. This program should address rehabilitation of existing sewers, new relief sewers, lift stations, and wet weather overflows.

Process benchmarking looks at how to close the gap, improve knowledge, practices and procedures. It would typically include: identifying what is to be benchmarked, defining the problems, identifying comparable utilities, collecting the data, determining the current performance and projecting future performance, communicating the benchmark finding and establishing goals, developing and implementing an action plan, monitoring progress, standardizing the improvement, and recalibrating the benchmark.[21]

The benchmarking process requires managers of a public owned treatment works to gather financial data and other operational and maintenance information that will be used for statistical analysis. This procedure will determine quantitatively the costs for the service and efficiency of the utility compared to other facilities. After the financial data are compiled and standardized, the data can be compared to national financial data, operational information, maintenance data, process techniques, and costs.

Benchmark information can help define utility weakness, and areas that need improvement through cost comparison associated with individual processes, procedures, and policies. Some issues that can create major problem for a public owned treatment works are inflow, infiltration and sanitary sewer over-flows. These issues need to be taken care of as they arise and not when the state or federal government mandates compliance.

The City of Bismarck Water Utility Department participated in a benchmarking study in 1996 that was conducted by the Water Environment Research Foundation (WERF). This study demonstrated that wastewater collection and treatment costs would be reduced when processes are managed in a proactive manner and priorities are planned and prescribed appropriately through continuous improvement.

In this study the City of Bismarck water utility data were compiled from 1995 through 2000 to see if any trends were noticeable and if changes that were made since 1996 affected the costs of treatment. The process costs examined are related to wastewater operations, maintenance, and sludge disposal. Some statistical data that were compiled and standardized nationally were not available from the City of Bismarck financial data. The costs that were not available were shared services and outsourced services. Although the BWWTP uses shared and outsource services, the data was not available. The cost data that were not used were office supplies, equipment and material because as the data were tracked and plotted year to year it was obviously obscure, so it was not used. The total cost for office supplies for the year could easily be spent in any given month. The cost data that were used include: operations, labor, chemicals, power, biosolids and maintenance. The biosolids costs were further broken down to percent: labor, fringe benefits, power and equipment. From the total operations cost and plant flow data, the cost per million gallons treated per year was calculated and compared to national benchmarked data.

Benchmark information is not always straightforward and some interpretation of data will be required. When looking at yearly costs where there are no capital improvements or major expenditures, a POTW will appear to operate efficiently, whereas a POTW that has gone through recent major renovation will appear to have high utility costs. A new facility will initially have much less operations and maintenance costs, whereas a facility that is at its life expectancy will see higher costs associated with the wastewater treatment.

[21] Ibid

The vast majority of wastewater treatment facilities that participated in the national benchmark study treat much more flow than the BWWTP and many have to provide nutrient removal. The Bismarck WWTP does not have to remove nutrients or comply with nutrient limits and it has much lower flows than most of the cities that participated in the national benchmark study. This makes it hard to find data in which to compare apples to apples. Bismarck has indicators that do not match the national benchmarked data, because some of the information was so broad in expenditure category that it was hard to separate out costs and compare it to nationalized benchmarked data. When the data looked obscure, they were not used and left out of the overall picture. Factors like these will have to be weighed into the overall picture, when one looks at why a facility is or is not as efficient as other facilities.

Maintenance Optimization and Costs

Repairs and capital improvements require large expenditures of resources. These costs will be much larger when the system and process have to recover from neglect. These costs will be passed on to the customer in the form of water rate increases. A large increase in utility charges may cause a public outcry. They may demand something be done through the media and political process. Planning and budgeting for capacity and facility improvement will lessen the likelihood of large, sudden rate increases. Benchmarking shows that those facilities who use maintenance program management policy tend to operate more efficiently because managers operate proactively versus reactively.

Utilities that use maintenance programs will have an advantage and will likely be more efficient because the process assigns and tracks work orders, repairs, and preventative maintenance on a scheduled basis. It is normal for maintenance programs to do requisitions, and track inventory, labor, and equipment history. Past repairs to equipment will be readily available to assess the costs associated with each piece of equipment and this will aid maintenance decision makers determine when the equipment should be replaced and not repaired. Having a maintenance program will institute timely proactive preventative maintenance so equipment will seldom require reactive emergency repair and this will extend the useful life of the process equipment, reduce labor, and overtime costs.

The majority of time spent by maintenance personnel should be in the category of preventative maintenance – scheduled repairs versus the category of emergency repairs – unscheduled repairs, which would reduce or prevent emergencies in the first place. The organization should focus on programs like: valve exercising, lift station and force main flushing, flow testing, inflow and infiltration, pump station inspections and other preventative maintenance services. One of the principal benefits of pump station inspection is early detection of impending problems that could eventually cause failure of the pump station, if not corrected in a timely manner. Regular inspections also create an opportunity to perform the routine preventative maintenance tasks necessary to ensure that the equipment in the pump station does not fail. Similarly, forcemain inspection and monitoring also detect indications of impending problems and failure.

Benchmarking will identify maintenance categories that should be tracked by plant managers. Benchmarking will establish a baseline and quantify maintenance performance from which to measure future performance. For example, when maintenance expenses are tracked by categories that differentiate between proactive and reactive, this will inform managers the associated costs and degree in which equipment maintenance is proactive or reactive. This will require managers to breakdown maintenance expenditures between proactive (PM) and reactive (emergency repairs). Ideally, one would expect that as a facility increases its expenditures in the category of equipment preventative maintenance then there should be a decrease in the cost of emergency repairs. If maintenance costs increase for preventative maintenance, then the time for emergency maintenance should go down because in the end it is more efficient to be proactive than reactive. Proactive maintenance is always more cost-effective than reactive maintenance.

The City of Bismarck tracks equipment preventative maintenance and equipment repairs. The tracking of the hours spent and cost for purchases by category is the first step in identifying the costs associated with maintenance. It seems that the tracking of the true costs is a slow progressive step. The preventative and unscheduled maintenance cost data for 1995 and 1996 were so obviously low, that the data for those years were not used. The numbers continue to be bit sketchy when staff is questioned about the allocation of expenses relating to purchases and what hours of time are spent where. If one uses benchmarking to monitor these expenses, it will show how the maintenance department is either proactive or reactive to equipment maintenance. If total maintenance expenses decline and preventative – scheduled maintenance expenses increase, everything else constant, then it would indicate that the maintenance department is doing more scheduled maintenance and thus is more proactive. Some benefits to being proactive in equipment maintenance are that it ensures the availability and reliability of the equipment, and it maintains the value of the investment. If maintenance of equipment is not managed, equipment will deteriorate through normal use and age and the value of the capital asset will be lost.

Table 1. Scheduled versus unscheduled maintenance at the Bismarck WWTP

Year	1995	1996	1997	1998	1999	2000
Equipment P M			$20,827	$30,735	$23,423	$20,536
Unscheduled equipment repairs			$14,263	$28,351	$34,315	$54,326

The large increase in the unscheduled equipment maintenance in 2000 could be explained by a number of reasons. First, which is the most likely, the BWWTP is approaching its life expectancy. Wastewater treatment plants deteriorate rapidly and there have not been any capital improvement projects to the BWWTP since 1987 to increase its capacity. The BWWTP was built in 1987 and it was designed to last until 2003. As the facility ages, the maintenance of it increases rapidly. Toward the end of the facilities' life expectancy, the whole plant can start to fall apart at the same time and the scheduled maintenance can be overwhelming. When a facility gets behind with scheduled maintenance, it may take several years to catch up, which will affect the emergency maintenance category. Maintenance that should have been in the scheduled category can end in the emergency maintenance category and reduce plant efficiency.

Second, the high flows in 1999 may have taken it toll on the facility and the maintenance costs did not show up until 2000. Third, the maintenance staff did not do enough equipment preventative maintenance in 2000. The scheduled maintenance cost decreased 14% from 1999 to 2000. This may have affected the emergency maintenance costs, which increased 63% from 1999 to 2000. Fourth, it is not clear that the staff has been allocating the man-hours to the right category when differentiating between equipment PM and emergency repair. The labor hours indicated on time sheets may not accurately reflect the time performed doing scheduled versus unscheduled equipment maintenance. Fifth, it is not clear that the maintenance purchases were designated to the correct category. The old allocation system for tracking costs for purchases was cumbersome at best. For example, when the city shop, another section in public works, performs maintenance on plant maintenance or biosolids equipment, all the associated labor and purchases for its repair was not available.

In June 2002, the BWWTP changed its allocation categories for all plant expenditures. Administration and plant managers will need to make a clear distinction to staff how and where to allocate expenditures. They need to communicate the difference to the maintenance and operations personnel performing equipment PM and emergency repair by providing training how to interpret the difference and communicate the importance of tracking the man-hours and purchases to the correct category. This new system, when used correctly, may help to define scheduled and emergency expenses. If not, the data may be questionable, as it is now, for making such predictions as to why the costs increased or decreased in particular categories.

Operational Costs of the Bismarck Waste Water Treatment Plant

Operational indicators can be used to assess utility performance. Labor options for the treatment of wastewater come in a variety of forms from privatization of operations, maintenance, or laboratory functions, private ownership, to contracting out certain specialized services. The private sector is generally used to design and build wastewater systems and then leaves it up to the local government to manage and control the wastewater treatment and systems. Bismarck wastewater treatment (BWWTP) operations, maintenance, and laboratory services are done by staff employed by the city. Maintenance work is contracted out to local business when specialized skills are needed. These special skills are generally related to mechanical, heating, and air conditioning. In addition, when new electrical power equipment is installed, the wiring is normally contracted out to private industry by bids or quotes. This system of contracting out is cost efficient because if certain skills are needed on a limited basis, then there is no need to hire a full-time staff for the work or provide training that will be lost due to not using the skills often enough, as well as having to procure equipment that will rarely be used.

The labor and operational costs per million gallons treated have remained relatively constant at the BWWTP over the last five years as indicated by Table 2 and Chart 1. The total operations costs are on the rise and it is expected that this trend will increase because the plant is approaching its expected life, and there are currently excessive suspended solids loadings to the BWWTP. From 1998 through 2001, the BWWTP has been operating at 110 % or greater of its design capacity for suspended solids. Additional resources are now required for settling and pumping the suspended solids, biosolids digestion, and storage. The first part of Table 2 quantifies the total plant operation costs for processing and handling the wastewater once it has arrived at the BWWTP. The second part of table 2 quantifies the labor, chemical, power, equipment, and operations costs. This second part is the total cost for each area divided by the average annual flow in millions of gallons. Therefore the amount is what it costs to treat each million gallon for a year of flow. These data are standardized so that they can be compared to the national benchmarked data. The national benchmarked data are for the year 1995. The city of Bismarck data for this table are for the years 1995 through 2000. Part 3 of Table 2 gives the operations cost/million gallons per day (MGD) for the last 6 years of available data.

Table 2. Operation, labor, chemical, power and equipment costs for wastewater treatment.

Total Operation Costs for Bismarck WWTP

Year	1995	1996	1997	1998	1999	2000
Total operations cost	$853,186	$857,053	$809,980	$806,299	$992,412	$949,016

Unit Operation Costs (Costs are in dollars /million gallons/day)

Bismarck WWTP and National Benchmarked Data

	Bismarck	Bismarck	National	National	National
Year	1995	2000.	Avg.	Low	High [22]
Labor	$53,633	$54,676	$75,441	$6,557	$190,995
Chemical	$9,248	$12,019	$11,070	$65	$10,293
Power	$17,083	$18,610	$31,020	$6,245	$78,203
Equipment/Material	$2,267	$14,628	$11,696	$776	$38,024
Operations cost per MGD	$135,579	$147,654	$175,000	$22,000	$437,000

City of Bismarck Unit Operation Costs /million gallons/day

Year	1995	1996	1997	1998	1999	2000
Operations cost/MGD	$135,579	$166,325	$127,839	$156,136	$136,320	$147,654

[22] Patrick, Roger, Janet, Rompala et al, *Benchmarking Wastewater Operations – Collection, Treatment, and Biosolids Management*, Water Environment Research Foundation Project 96-CTS-5 1997

Table 2 demonstrates how Bismarck compares with the national low, high and average cost facilities when the cost data are calculated for a per millions gallons per day average for a year. Costs are in dollars per million gallons treated for each year average. The low costs are for utilities (using 1995 national data) that would be the most efficient and the high costs would be for utilities that are the highest cost for labor, chemicals, power, equipment/material, and operations cost per yearly average million gallons per day. Low cost would be the most efficient benchmarked utility and high cost would be the least efficient. As expected, due to the aging plant and increasing inflow and infiltration, the BWWTP cost trend is upward for treating the wastewater on a million gallons per day basis from the year 1995 to 2000.

From table 2 it is evident that the City of Bismarck WWTP operates below the average cost per million gallons treated or viewed as an efficient facility. There is a large difference between the low and high cost facilities. Many variables affect the cost per million gallons treated. The treatment plant may be at its life expectancy and the operational cost may be much higher than a facility that has been recently expanded and upgraded. It may depend in part on such factors as the complexity of the treatment process and size of the plant. Therefore, depending upon the size and complexity of the treatment plant, the benchmark for cost per million gallons treated could be easy or almost impossible to achieve.

Table 3. Percent of operations cost by category versus national benchmarked data.

Percent of Average Operation Costs

	Bismarck	Bismarck	National	National	National
Year	1995	2000	Avg.	Low	High [23]
Labor	43.3%	39.0%	43.1%	23.2%	74.3%
Fringe benefits	5.1%	5.5%	13.7%	6.5%	27.3%

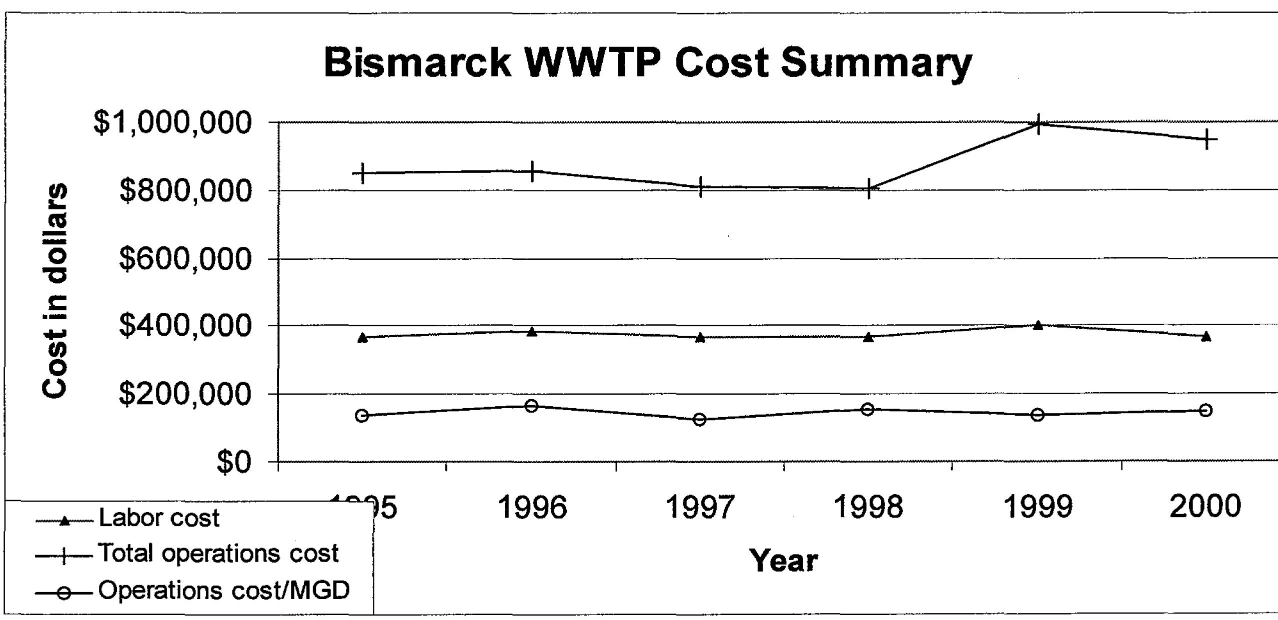
[23] Ibid

Percent of Average Operation Costs

Year	Bismarck 1995	Bismarck 2000	National Avg.	National Low	National High
Chemical costs	7.5%	8.6%	6.0%	0.1%	23.8%
Power costs	13.8%	13.3%	19.1%	4.6%	39.8%
Equipment	1.8%	10.4%	7.0%	0.7%	15.5%

Table 3 again shows that the Bismarck wastewater facility is efficient when compared to the national average. The baseline or benchmark indicator for labor cost has remained constant per MGD. This stable cost is due to what the City of Bismarck did when they reorganized some of the management structure in 1996 as it lowered the overall labor cost per MGD in 1997. This is shown in chart 1. As a result of the reorganization, the facility hired more part-time help, reduced full-time staff while giving more assignments to the existing management and staff. That has reduced the labor costs per MGD, but now the operations costs are on the rise per MGD.

Chart 1. Bismarck WWTP operation, labor and cost per million gallons treated.



The spike in 1999 for total operation cost is due to an increase of flow from 6.43 average million gallons per day to 7.28 million gallons per day for the calendar year. This increase was mainly due to higher inflow and infiltration into the collection system. With the use of benchmarking management can gauge their performance controlling inflow and infiltration (I & I). When the I & I become so large, managers will know when something needs to be addressed.

Chart 2. The City of Bismarck WWTP and wastewater collection expenses and wastewater revenue.

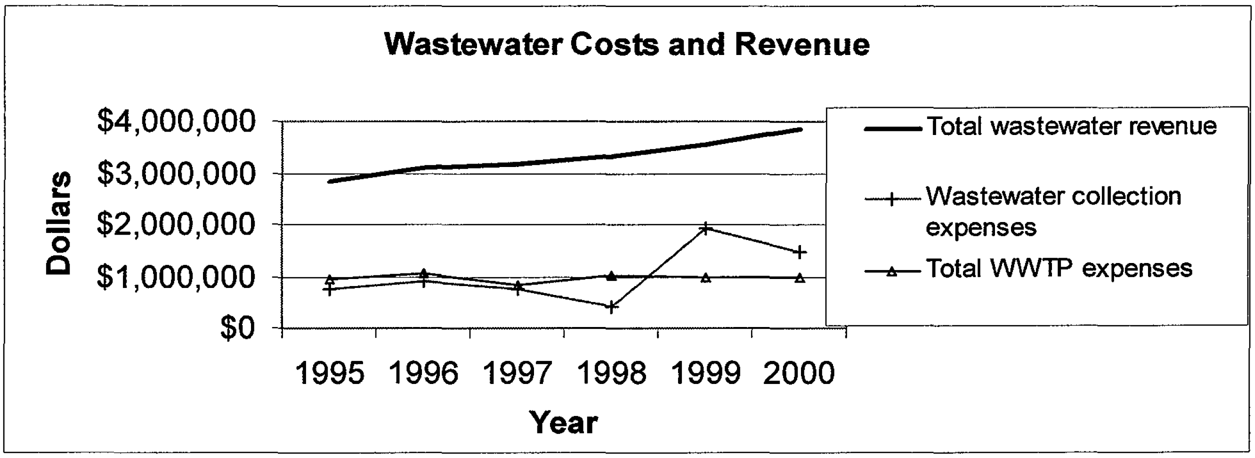
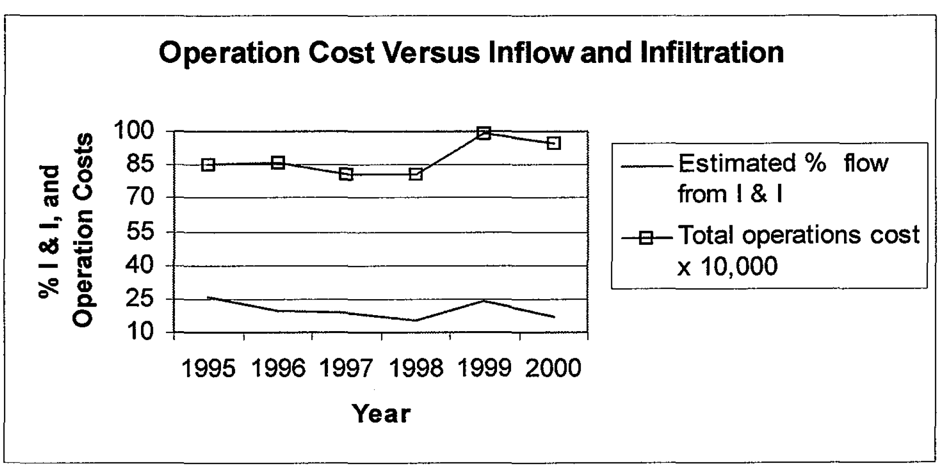


Chart 2 shows the total wastewater revenue and total wastewater costs. The costs for wastewater are from costs of the collection system and wastewater treatment. The spike in 1999 for the collection system cost is from rehabilitation of part of the collection system. These expenses are an improvement in the infrastructure that is aimed at holding down infiltration through leaky pipes.

Chart 3. Operation costs versus inflow & infiltration.



The spike in the operation costs on Chart 3 in 1999 is probably due a large increase in I & I to the collection system. Everything that enters the collection system ends up at the wastewater plant unless the sanitary sewer collection system has a sanitary sewer overflow and this runs into the storm sewer system or the collection system bypasses raw sewage directly to the river. As the flow to the wastewater plant increases, so do the operation costs of treating the water. The extra costs are due to having to pump the extra water several times, handling extra solids, adding additional chemicals for the treatment and/or overtime of staff that have to remain on site for dealing with high flows. The estimated amount of inflow and infiltration jumped from 16 percent of the average annual flow in 1998 to 24 percent in 1999. This peak is illustrated in Chart 4, which demonstrates the impact of I and I to the BWWTP operation cost.

Benchmarking provides a baseline and a gauge for the ongoing flows to the wastewater treatment plant from I & I. When the I & I becomes larger than about 18 percent, the collection system should research further, flow from rain seepage and ground water through sump pumps from the rain events. The BWWTP influent has seen its daily average flow double from high rain events. These high flows can remain until it stops raining. However, the flow gradually subsides over a period of weeks to months depending on the amount of rain. The initial peaks are probably due to the defects in the gravity sanitary sewer system and storm water from surface drainage. The gradual subsiding of flow is probably due to sump pumps connected to the sanitary sewer system, pumping ground water. Current Bismarck city ordinance prohibits sump pump connections to the sanitary sewer, however the City does not enforce this policy. Although these connections are against city ordinance, someone needs to educate the public that doing so is illegal and that it causes undue hardship to the collection system and the wastewater treatment plant.

Extreme conditions to the sanitary sewer from rain event may cause sanitary sewer overflows (SSO). This is where the sanitary sewer system can no longer handle the flow without flooding homes with sewage. When the Bismarck sanitary system approaches a level where they know they will flood homes with sewage, operators can bypass the sewage directly to the Missouri River without treatment. The choice is to flood peoples homes or being out of compliance with EPA regulations pertaining to SSO. I and I waters should go through the storm sewer system and not the sanitary sewer. When large amounts of storm water or ground water enter the sanitary sewer system, it should be addressed with priority.

When benchmarking is used it will provide a baseline I & I and collectively assess the sanitary sewer system and wastewater treatment requirements. It will inform the collection system and the wastewater treatment managers of any shortcomings and the need to prioritize the problem areas. With these policies in place, the collection system should prevent any sanitary sewer overflows. In addition, when the collection system does prevent high I & I, the wastewater treatment plant is more likely not to have to bypass any treatment or route the water to emergency storage.

Biosolids Cost and Model

The biosolids costs are those cost that are necessary for biosolids removal and disposal from the BWWTP after they are processed. These cost arise when the biosolids are hauled and injected into land for recycling. Benchmarked biosolids costs included the depreciation cost for vehicles used for transporting and disposal, fuel, oil and maintenance for the vehicles, labor, soil testing and biosolids testing.

Table 4. Bismarck wastewater treatment plant biosolids data and hauling costs per ton.

Bismarck wastewater treatment biosolids costs

Year	1995	1996	1997	1998	1999	2000
Tons hauled	615	560	631	584	784	669
Total biosolids cost w/dep	$35,704	$30,457	$40,588	$39,653	$46,803	$56,990
Biosolids cost/ton w/ veh dep	$58	$54	$64	$68	$60	$85

The costs for the Bismarck biosolids program are on the rise due to an increase in the hauling distance, biosolids equipment purchases, and labor costs. The availability of city land that is in the proximity of the WWTP is decreasing, due to development within the City of Bismarck and its vicinity. This has made the hauling distance from what was normally about 5 miles from the plant to as much as 22 miles one way for biosolids disposal. In addition, increased labor costs are required to haul the biosolids and more equipment is needed to transport the biosolids. The longer runs have also increased the equipment maintenance and fuel costs. When the biosolids cost are benchmarked, it is evident that the costs are rising and that the trend will continue to rise. When managers see the trend through benchmarking an investigation should take place to look at the costs and how to hold them down.

Chart 4. Biosolids costs per dry metric ton hauled and tons hauled for each year.

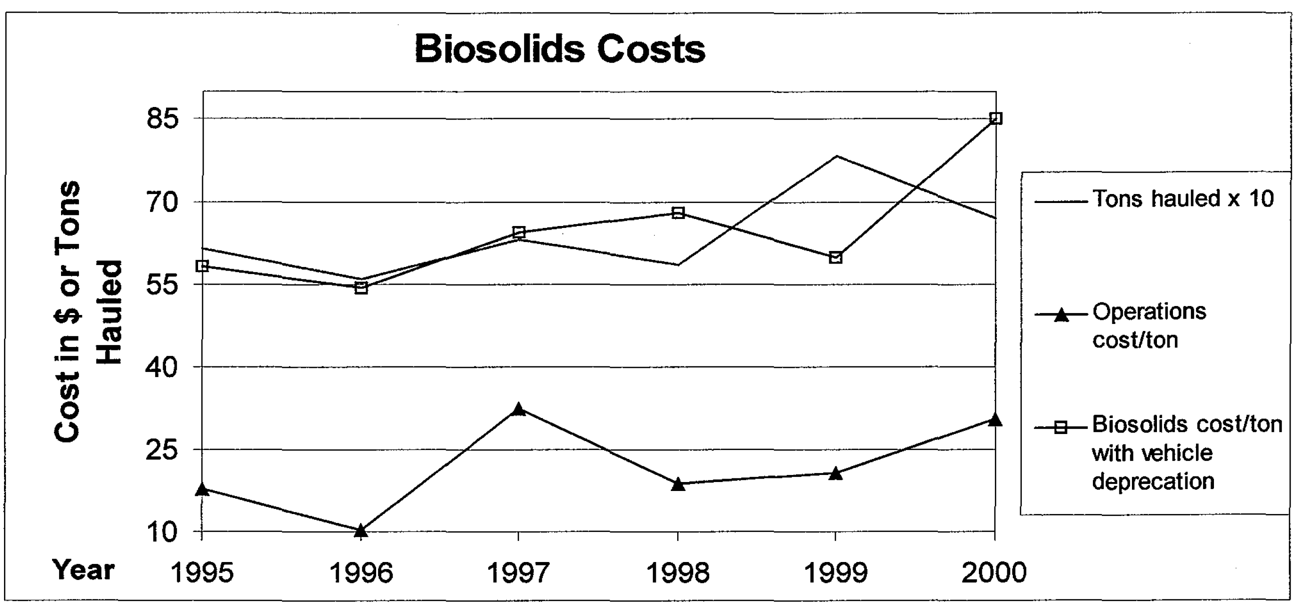


Table 5. Bismarck wastewater treatment plant biosolids costs by category in percentage verses national benchmark data.

Biosolids Costs	% Of Average Operation Costs					
	Bismarck WWTP			National data for 1995 Benchmark [24]		
	1995	2000	6 yr. Ave.	Avg.	Low	High
Labor	43.3%	39.0%	41.5%	43.1%	23.2%	74.3%
Fringe benefits	5.1%	5.5%	5.1%	13.7%	6.5%	27.3%
Chemical costs	7.5%	8.6%	8.4%	6.0%	0.1%	23.8%
Power costs	13.8%	13.3%	12.4%	19.1%	4.6%	39.8%
Equipment	1.8%	10.4%	6.8%	7.0%	0.7%	15.5%
Shared services				7.4%	0.0%	29.5%
Outsourced services				7.2%	0.2%	34.7%

The data are from the City of Bismarck for years 1995 and 2000 and the average from 1995 to 2000. The 1995 benchmark data include the average, low and high cost benchmarked utilities that was done by the Water Environment Research Foundation.

Table 6. Wastewater and Biosolids Cost Model for the Bismarck Wastewater Treatment Plant

	1995	1996	1997	1998	1999	2000	Ave.
Dry tons biosolids/day/MGD	0.2787	0.2469	0.2721	0.2580	0.3057	0.2807	0.27
Cost per KW (cents)	4.30	4.30	4.30	4.30	4.30	4.30	4.30
MGD EXP 1.354	13.64	12.45	12.82	12.43	14.70	13.32	13.2
WBPLA	0.54	0.56	0.56	0.56	0.53	0.55	0.55
BIOPROD hauled	0.59	0.57	0.59	0.58	0.62	0.60	0.59
WBWAGE	180.65	184.00	175.25	179.14	179.10	173.75	179.63
Predicted Value	\$812,327	\$743,018	\$750,045	\$735,473	\$876,936	\$771,850	\$783,560
Total expenditure, w/o CIP	\$853,186	\$857,053	\$809,980	\$806,299	\$992,412	\$949,016	\$907,937

[24] Patrick, Roger, Janet, Rompala et al, *Benchmarking Wastewater Operations – Collection, Treatment, and Biosolids Management*, Water Environment Research Foundation Project 96-CTS-5 1997

Wastewater and biosolids cost model:

$$OPCSTWET=e^{6.43} \times (MGD^{1.354}) \times (WBPLA^{-0.493}) \times \{[(ASOXY/100)+1]^{0.442}\} \times \{[(ASMEC/100+1]^{0.404}\} \times (BIOPROD^{0.408}) \times (WBWAGE^{0.499}) \times (KWH^{0.342})$$

Where:

OPCSTWET = Total cost of wastewater and biosolids operations, in dollars
MGD = Average daily flow in million gallons per day
WBPLA = Average daily flow per plant (both wastewater and biosolids) operated in MGD/day
ASOXY = Percentage of influent treated by the activated sludge process using pure oxygen
ASME = Percentage of influent treated by the activated sludge process using mechanical aeration.
BIOPROD = the quantity of biosolids produced per unit of influent (dry ton/Mgal/day).
WBWAGE = Average wage of a worker in wastewater and biosolids operations ($)
KWH = Cost per kWh of electricity. (Cents)[25]

This model can be used to predict the total costs of wastewater and biosolids operations. The formula incorporates: flow (MGD), if the wastewater treatment process uses activated sludge (ASME) and if it is with pure oxygen (ASOXY), biosolids produced (BIOPROD), average wage of workers per MGD (WBWAGE), and the cost of electricity, which is 4.3 cents per kWh (KWH). The largest impact to the BWWTP cost model is from flow, then employee wages, followed by biosolids production and then the cost of electricity. Since the BWWTP does not use activated sludge (ASOXY) or pure oxygen, (ASME) they have no effect on the calculation. Certain treatment processes make some facilities more costly than others do. Using activated sludge, pure oxygen for activated sludge, or treating the wastewater in an area that has high electrical costs can dramatically increase the operations costs for a WWTP.

The gap is growing between the predicted costs and the actual costs to operate the Bismarck WWTP. The biosolids model does not consider all the factors that affect costs. For example, the Bismarck WWTP has to process its biosolids more than twice before they are removed from the system. A cold climate WWTP like Bismarck could expect to spend considerably more for heat than a warm climate WWTP. These and other factors are not calculated into the overall picture for the model. The spike in the predicted cost for 1999 is probably due to an increase in the flow to the

[25] Ibid

treatment plant from inflow and infiltration. If this flow were benchmarked over the years, management would see that something needs to be corrected.

The greater the suspended solids entering the wastewater treatment plant the more that have to be transferred, treated and disposed of. After these suspended solids are treated, they are called biosolids and then recycled through agriculture. The BWWTP has seen the window narrow for when the biosolids can be applied to agricultural land. This narrow window has limited when the WWTP can haul and as a result it encourages equipment operators to work as much overtime as practical when the weather and hauling conditions permit disposal. In 2002, the City of Bismarck hired a consulting engineering firm to address some of the shortcomings with the biosolids program and policies.

Odor Identification, Costs for Treatment and Optimization

Metric benchmarking looks at how much, where, and when. It uses independent variables or explanatory factors to determine high or low cost treatment. High cost wastewater facilities may inherently adapt certain traits such as not providing for corrosion and odor control. Managers need to investigate and solve this problem to optimize its operation. Managers need to identify the problem, investigate and research possible solutions, implement the best solution, and then continue to monitor progress and make additional changes as needed. To recommend an optimized odor control policy for the Bismarck Wastewater Treatment Plant, a cost benefit analysis was performed. A separate cost benefit analysis was done for controlling odors in the air and one for controlling hydrogen sulfide in water.

Odors, particularly when associated with hydrogen sulfide, are a potential indicator of corrosion. The City of Bismarck has had and still does have problems with hydrogen sulfide. The pretreatment building that was built in 1982 for about 1.5 million dollars will probably have to be torn down and replaced due to surface corrosion and structural deterioration done by hydrogen sulfide gas. This deterioration was caused from previous elevated hydrogen sulfide gas levels in this building and continued gas exposure to the cement and within these cement/metal reinforced structures. Hydrogen sulfide gas problems should be thoroughly investigated to determine the cause and to identify appropriate preventative activities to reduce the problem. Odors generated in the wastewater system may require special treatment and strategies, depending on where and how they are to be treated. Many processes and technologies exist that can reduce these odors. In addition, different strategies and treatment are used depending on where and how the odors are generated. Independent research was conducted on identifying odors and ways to reduce odors.

Laboratory testing will indicate if an idea may be practical. If the test works in the lab then a pilot scale study can be set-up, with support from the lab. This in-house capability has made it easy for the WWTP to evaluate the process modifications that have been initiated and to look at odor control chemicals and prevention strategies that have been suggested. Testing has allowed the WWTP to avoid large numbers of products that have been suggested, but were either ineffective or too costly when tested in the lab. Many times the proposed product does not work effectively for the application in which it is being tested, but the experimentation involved often leads to other ideas or applications that can be utilized.

Of all the gasses in wastewater, the main one of concern for public works water utility managers, wastewater workers, and customers is hydrogen sulfide. Inhibiting hydrogen sulfide production and removing it once it is generated is important because it is extremely toxic at high concentrations, it causes odors at extremely low concentrations, and it is corrosive to metals.

Odors, particularly when associated with hydrogen sulfide, are a potential for customer complaint. Foul odors released during the collection and treatment process can cause neighbors and/or customer pressures to provide additional treatment. They may demand something be done through the media and political process. Ineffective and inefficient odor control management practices that do not consider all reasonable options, use scientific evidence, and cost-benefit analysis may mean that managers may not spend their resources wisely or even solve the problem. Wastewater treatment and odor control processes that are not managed scientifically will provide treatment at higher costs now and in the future.

Problems Caused by Hydrogen Sulfide

Customers living close to wastewater collection and treatment facilities will be in full support of a program that is started or expanded to reduce odors. If customers smell strong odors coming from these systems, they may think there is a treatment problem, and that something should be done to correct it - now. Hydrogen sulfide (H2S) gas is a common odor problem in sewer pipes, at wastewater lift stations, and treatment plants. Other gasses like ammonia, mercaptans, amines, indoles and fecal odors may be a problem too, but usually H2S is the most common culprit. Hydrogen sulfide is readily distinguishable by its rotten egg odor, which can be detected by the human nose at less than 0.02 parts per million (PPM). Odor complaints can happen at any time, but most complaints for Bismarck arise when the gas "is emitted" from treatment works during cool evenings when the ground is warm, the water is warm, and there is a slight wind blowing the air toward nearby residents. Some people are sensitive to the H2S gas and when it becomes intolerable to them, they call plant staff, public works administrators, and city officials about the odors coming from these systems.

Hydrogen sulfide is a toxic gas, which can be hazardous to wastewater workers. Hydrogen sulfide is slightly heavier than air and once generated it will accumulate in enclosed, poorly ventilated, and low-lying areas. These conditions can lead to hazardous working conditions for workers.

Hydrogen sulfide gas is corrosive to metals such as iron, zinc, copper, and lead at low levels. Wastewater treatment and collection buildings under the influence of hydrogen sulfide gas will require increased maintenance costs associated with maintaining the pumping equipment, wiring, and metal plumbing. When sulfides react with the moisture present in the air, it forms sulfuric acid, which will corrode paint, concrete, and metals in lift stations and the treatment facility. This corrosion will reduce the life expectancy of the buildings, piping and equipment. Eventually, capital costs to repair or replace wastewater treatment equipment, systems and processes will be required sooner than expected if the hydrogen sulfide levels are not controlled. Management can pay now to resolve odor problem or pay much more later for deteriorated systems, equipment, and processes.

Identification of the Sources of Odors and Hydrogen Sulfide in Wastewater

Before management can solve a problem, they have to determine the cause. Through investigation it has been determined that the majority of the hydrogen sulfide production in wastewater arises when is it transported through the collection system to the wastewater treatment plant. Most of the hydrogen sulfide generation occurs when the water is transported and held in force mains, lift stations, sunken sewer pipes, and during low wastewater flow conditions. Force mains are a normal part of most sanitary sewer systems where the wastewater is pumped. Force mains are wastewater pipes that transport sewage, which are completely full, and do not allow any air movement across the surface as a gravity line would. Most H2S formation occurs within the slime layer on the force main pipe walls.

Possible Solutions for Controlling Hydrogen Sulfide in the Liquid Phase

Now that management knows the cause, the next optimization step is to determine the possible solution to controlling hydrogen sulfide formation. Preventing the formation of hydrogen sulfide and other odors in wastewater can be accomplished by many different techniques and strategies. Improved maintenance, operations, and housecleaning practices can aid in reducing the odors. Maintenance practices that are used for controlling hydrogen sulfide include replacement of sunken sanitary sewer pipes, and jetting of the sanitary sewer pipes in the system. Operational practices include flushing of wastewater channels, lift stations, and scum pits. Good housekeeping and cleaning processes that remove grease, solids and debris buildup on equipment and conveyors will reduce odors.

Chemical cleaning of the wastewater force mains and lift stations can reduce hydrogen sulfide generation. Testing has demonstrated that caustic soda cleaning has been effective in reducing H2S formation up to 75 percent immediately. However, H2S production in the force main will normally increase back to where it was after a couple of weeks, depending on the wastewater temperature.

Chemical additions may not be applicable to all systems. If a wastewater treatment plant were having an ammonia problem, then ammonium nitrate would not be a viable solution. Some chemicals are more environmentally friendly and this should be a factor when deciding over equally efficient chemicals.

Chemical oxidizers like sodium nitrate, calcium nitrate, hydrogen peroxide, potassium permanganate, ammonium nitrate, and chlorine can reduce or inhibit sulfides in the wastewater. Oxidizing chemicals can also reduce the H2S already present in the wastewater stream. Iron salts such as ferric chloride can be added upstream, which can tie up the H2S through precipitation. The City of Bismarck wastewater plant employees performed a pilot study on several force mains.

Chemicals tested included calcium nitrate, sodium nitrate, potassium permanganate, chlorine, and bleach. Some of the data that were used for the cost-benefit analysis were from jar testing performed at the WWTP laboratory. Below in table 7, is a list of some of the chemicals that were tested for odor control in the liquid phase. The table includes their formulas or type of product, chemical costs per pound, the cost in dollars for the chemical to treat one pound of dissolved hydrogen sulfide and the cost for the chemical to treat one million gallons of wastewater at three milligrams per liter hydrogen sulfide.

Labor costs are expensive, so managers will want to consider the labor cost involved in chemical feed systems. The Bismarck wastewater utility had added sodium nitrate in the collection system in the solid form, which requires increased labor costs. Calcium nitrate comes as a liquid, costs more per pound, but has less associated labor costs, which makes it about as cost efficient to use as sodium nitrate for H_2S control.

Table 7. Chemical costs for treating hydrogen sulfide in water

Chemical	Chemical Type or Formula	Estimated Cost/ Pound of Chemical	Estimated Cost to treat 1 pound of Dissolved Sulfides	Estimated Chemical Cost/yr./mgd at 3 ppm H2S
Calcium Nitrate, liquid	CaNO3	$ 0.37	$ 2.99	$ 27,000
Chlorine gas	Cl2	$ 0.30	$ 0.96	$ 8,700
Chlorine liquid or dry	CaHCLO3	$ 2.00	$ 6.40	$ 58,000
Chlorine dioxide	ClO2	$ 1.25	$ 1.12	$ 10,000
Ferric Chloride	FeCl3	$ 0.60	$ 6.36	$ 58,000
Hydrogen peroxide	H2O2	$ 0.50	$ 84.00	$ 770,000
ML-50	Enzyme	$ 10.00	$ 56.00	$ 511,000
Potassium Permanganate	KMnO4	$ 2.00	$ 12.40	$ 113,000
Potassium Hydroxide	KOH	$ 0.68	$ 21.12	$ 193,000
Sodium Carbonate	Na2CO3	$ 0.30	$ 6.24	$ 57,000

Recommended Solution for controlling Hydrogen Sulfide Efficiently in the Wastewater

Management can look at Table 7, and see that gas chlorine would be the most efficient method of controlling hydrogen sulfide at the Bismarck Wastewater Treatment Plant. It would cost $8,700 per MGD or $58,000 per 6.7 MGD to treat three mg/l of hydrogen sulfide. The last 5-year flow average for the BWWTP was 6.7 MGD per day. When this is contrasted to what the BWWTP added before testing, using potassium permanganate it would have cost $757,000 for the same result, but the costs for effective treatment were prohibitive. These costs are not the total costs because the odor control program is reduced in the winter due to lower hydrogen sulfide levels at the headworks and the cost figures would not be quite that high. Benchmarking data and performing a cost-benefit analysis makes it easier for management to incorporate best practices into an odor control program.

Possible Solutions to Controlling Hydrogen Sulfides and Odors in the Air

Since we already talked about the cause of hydrogen sulfide formation, the next step for an efficient odor control program controlling hydrogen sulfide discharges into the air is to determine the possible solutions. There are several options that management should considerer. A brief description of some common methods are described below. Wet scrubbers can be used to reduce or eliminate hydrogen sulfides and other odors in the collected air. A wet scrubber can use acids, alkalis, chlorine, chlorine dioxide, potassium permanganate, hydrogen peroxide, or ozone in a spray chamber to react with the incoming air. Scrubbers may be used for water-soluble gases such as hydrogen sulfide, ammonia, amines, organic acids and chlorine compounds.

An alternative to chemical treatment is to use a biofilter. Biofiltration can be used to reduce hydrogen sulfide, and eliminate other offensive wastewater odors. Organic material in a biofilter will consume odors through sorption, biological oxidation, and chemical oxidation. A typical biofilter media may consist of soil, sludge compost, wood chips, bark, or other organic wastes. The advantage of using a biofilter is that it is probably the most cost efficient process and it is environmentally friendly. Some of the disadvantages are that it requires a large amount of area, water and nutrient addition and some inlet heating during winter months. New technologies in the biofilter development have reduced the space requirements and only require the addition of plant effluent for wetting. Research on biofilter media has demonstrated that porous lava rock is one of the most efficient for hydrogen sulfide removal.

A second alternative to use that does not use chemical treatment is carbon. Adsorption products like carbon can control odors and hydrogen sulfide. Granular Activated Carbon (GAC) adsorbs hydrogen sulfide and Volatile Organic Compounds (VOC's) to its surface. Some disadvantages of using GAC are that it is a high cost system, has nonspecific binding, requires frequent maintenance and needs two separate systems. Two systems are needed during times of regeneration, when one of the systems is isolated during maintenance. Influent wastewater VOC concentration is hard to quantify and predict. High VOC concentration will require more frequent GAC changes than expected, especially if only H2S concentrations were used for design. Moreover, moisture will fill some of the void space in carbon, which will reduce GAC efficiency.

A third alterative and the current BWWTP strategy is to add chemicals directly to the exhaust air from the building emanating the odors. Chemical misting systems add chemicals or odor-neutralizing products directly to the foul air. The mists can be added to the wastewater treatment buildings, ventilation system or added to the surrounding areas. The odor-neutralizing products used in misting systems generally reduce the odor intensity and not the measurable hydrogen sulfide concentration. Masking agents can be added to the air by different methods, but have had limited success in combating strong odors. Masking agents are normally considered a temporary solution to odor control.

Prevention of hydrogen sulfide and odors can be started up front with facility and system design. Pipe sizes should be used that will transfer the wastewater in as short of time as practical. Engineers designing pipes may want to consider installing two smaller force mains for developing areas that will initially have low flows. Many years later when the flow demand requires it, the second lateral pipe can be placed in service.

Combinations of odor control strategies can be used: iron salts used with ozone, or nitrates with chlorine, or carbon and ozone. Approaches to controlling odors are numerous with new strategies and technologies being developed continuously. No single approach works best. Each system should consider the intricacies of each individual problem pipe or system and do the research to see what will work best for it.

Management can consider several good processes for removing hydrogen sulfide from the air. A scrubber or biofilter can be used to remove the hydrogen sulfide in air effectively and efficiently. Both of these systems appear to be cost efficient strategies that could be used at Bismarck's WWTP treatment headworks.

Table 8. Capital and chemical costs for treating hydrogen sulfide in air[26]

	Capital Costs	Chemical Costs/yr.	M^3 /min.	Ft^3 /min.	10 year Cost **
Wet Scrubber	$77,000	$19,500	280	9880	$426,000
Ozone	$67,500		280	9880	$560,000*
Activated Carbon	$128,000	$48,000	280	9880	$860,000
Composite filter	$89,000	$ 3,000	280	9880	$297,000

[26] Design Manual - "Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants" EPA/625/1-84/018 Center for Environmental Research Information U.S. Environmental Protection Agency Office of Research and Development Cincinnati, OH 45268 October 1985 The capital and chemical costs for H2S control are in 1984 dollars for cubic meters per minute and cubic feet per minute of air treated.

*This is an estimated cost for treatment assuming that the wastewater influent H2S concentration is at 3mg/l, the flow is at 7.25 million gallons per day and that it costs $0.54 for the electricity to remove each pound of H2S.

** This includes the initial capital cost and the chemical costs that would be required for 10 years of operation. The cost is what it would cost Bismarck to treat the estimated 30,000 cubic feet per minute of air discharged from their pretreatment building.

Recommended Solution for controlling Hydrogen Sulfide Efficiently in Air

The most cost-efficient option as indicated from Table 8, would be a biofilter. The City of Bismarck has adequate space for this type of process. Further study would be needed to verify true costs for this and other systems. In addition, new technologies are continuously being developed, which should be considered and evaluated.

Summary

Benchmarking is a process that searches for and applies best practices, innovative ideas and highly effective operating procedures into procedures and policies. It can be used to improve water utility effectiveness and efficiency. Benchmarking can help to define system and process weakness, which will provide valuable information on how to reduce costs and optimize the treatment process. Benchmarking is a learning experience. It compares operational practices to what other similar treatment facilities are doing now and projecting what that performance will be in the future.

Managers and city officials make decisions to spend resources. When these decisions are made with input from their employees and through scientific evidence that is obtained through research and studies, they will use their limited resources more effectively and efficiently. Data analysis will quantitatively determine the costs associated with the conveyance and treatment, which can be used to help determine the treatment costs now and in the future. When costs are benchmarked, it will provide management with information that will help them to prioritize needed improvements.

Performance management is a benchmarking method used to identify best practices and stimulate innovative ideas, which it then incorporates into the facility operation to make it effective and efficient. Indicators provide information about efficiency, liquidity and operational performance, but some indicators like investment can be very volatile from year to year, and affect the efficiency outlook, which should be considered in the overall picture.

It is the responsibility of local government to provide the utility the resources to ensure that the wastewater and its byproducts are treated effectively and that the wastewater treatment discharges meet the current federal standards. This requires managers to look at the entire system that influences the treatment and byproducts and to use the limited resources wisely.

Managers, employees, and city officials must plan to meet future demands and expansion requirements. Hydraulic overloading demands can be caused by new industry, infiltration, inflow, ground water through sump pumps, or by population growth. Industry, business, and non-point source pollution can cause wastewater pollution; monitoring is continuously required at various frequencies and points to provide scientific data that can be used for analysis, interpretation, and implementation of new policies or program development.

Environmental changes come in many forms from the mandated requirement from the Environmental Protection Agency, regulations by the State Health Department, to customer and citizen expectations. Increased requirements can come at a time when government organizations are expected to do more with less. The goal of benchmarking is to improve utility performance under a constantly changing environment.

Solving odor problems is not an easy task. What works for one facility may not work at another facility. What works in one pipe in the system may not work in another pipe in the same system because there are many variables that contribute to the hydrogen sulfide generation in the sanitary sewer pipes. The steps to solving the problem start at finding out where and what is causing the problem, followed by evaluating the options and costs, then establishing a plan of action and implementing it. The wastewater utility should consider all the viable options for each specific problem in the system and have them evaluated separately. No single strategy will be a panacea for all of the odor control problems for any wastewater collection and treatment system.

Finding the true cost and benefits of an odor control strategy is not straightforward. Chemical, electrical and equipment costs fluctuate depending on demand, location and vendors. Through research and evaluation, the most cost efficient strategy may depend upon which treatment processes are used, what ancillary equipment is available, and what biological processes may exist on site. The costs and effectiveness for an odor control system depend upon many factors that are unique to the situation. The cost benefit relationship for any odor control situation is case-specific. For each specific situation, a different set of parameters affects the total cost and therefore affects the cost/benefit relationship

It is challenging to find a universal set of indicators that describe efficiency, and obtaining comparable financial data for benchmarking comparison. Bismarck has indicators that do not match the nationalized benchmarked data and it is difficult to compare Bismarck with the larger facilities that were used in the benchmarking study. Data are not readily available and always accurate for some of the indicators. When the data looked obscure, they were not used and left out of the overall picture. In recent years, there have been changes to address the reliability of the data to be able to track it from year to year for trending. The usefulness of an indicator, and its likelihood to be monitored, varies. As the years pass, some of the data used for this study will change as well as increasing the usefulness of the data. The benchmarking study showed that there are wide differences among utilities, lack of consensus or best practices and questions of reliability of some data. Therefore additional benchmarking in the future should be considered and address some of these shortcomings. Additional research concerning the use of benchmarking and which indicators are most appropriate is needed.

BIBLIOGRAPHY

BOOKS

Arbour, Rick and Ken Kerri. Collection Systems: Methods for Evaluation and Improving Performance. U.S. Environmental Protection Agency Office of Wastewater Management, Washington, D.C.: 1998

Brueck, Terrance B. Developing and Implementing a Performance Measurement System: Volume I Project 99-WWF-7 Collection and Treatment, Water Environment Research Foundation. 2000

Design Manual. Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants EPA/625/1-84/018 Center for Environmental Research Information U.S. Environmental Protection Agency Office of Research and Development Cincinnati, OH 45268. October 1985

Desk Reference. The Clean Water Act, 25th Anniversary Edition, Water Environment Federation. 1997

Patrick, Roger, Janet Rompala, Adam Symkowski et al. Benchmarking Wastewater Operations – Collection, Treatment, and Biosolids Management. Water Environment Research Foundation Project 96-CTS-5. 1997.

INTERNET RESOURCES

Annual Report on Privatization, CUPE's Annual Report on Privatization – 1999. In the Public Interest. http://www.cupe.ca/pwannualreport.html

Clean Water Act Future Challenges. http://www.epa.gov/owow/cwa/future.html

The Clean Water Act. A Snapshot of Progress in Protecting America's Waters http://www.epa.gov/owow/cwa/25report.html

Houston-Benchmarking Wastewater Treatment Plant Operations. http://twri.tamu.edu/watertalk/archive/1998-Feb/Feb-5.2.html

Major Legislative Milestones In Protecting the Nation's Waters. http://www.epa.gov/OWOW/cwa/timeline.html

Peters, Tom, and Tammy Moseley. http://www.stfrancis.edu/ba/ghkickul/stuwebs/bbios/biograph/peters.htm

Water and Wastewater Facilities Will Benefit in a Deregulated Electric Utility Market. http://news.wateronline.com/content/news/article.asp?DocID={581BDCCA-99E2-11D3-9A6C-00A0C9C83AFB}&Bucket=Feature+Articles

Young, Kim, Transforming Government May 1998 http://www.privatization.org/database/PrivatizationProsAndCons.html

JOURNALS, NEWS ARTICLES AND TRAINING MANUALS

Davis, Gary. "Water and Wastewater Facilities Will Benefit in a Deregulated Electric Utility Market." November 1999.

Kristof, Dawn. “Utilities Strive to Optimize Purchasing Power. ” Water World. November 2001

Parkerm Mary A. “Case studies highlight improved performance for water Utilities.” Main Stream American Water Works Association, Vol. 45 No. 7. June 2001.

INTERVIEW

Fisher, John E. Short Elliot Hendrickson Inc. Telephone interview by author. July 1, 2002. Saint Paul, Minnesota.